Measurement of Directed Flow in $\sqrt{s_{NN}}$ = 200 GeV Au + Au, ~~d + Au~~, ~~p + p~~ collisions at RHIC - PHENIX

Hiroshi Masui

For the PHENIX Collaboration

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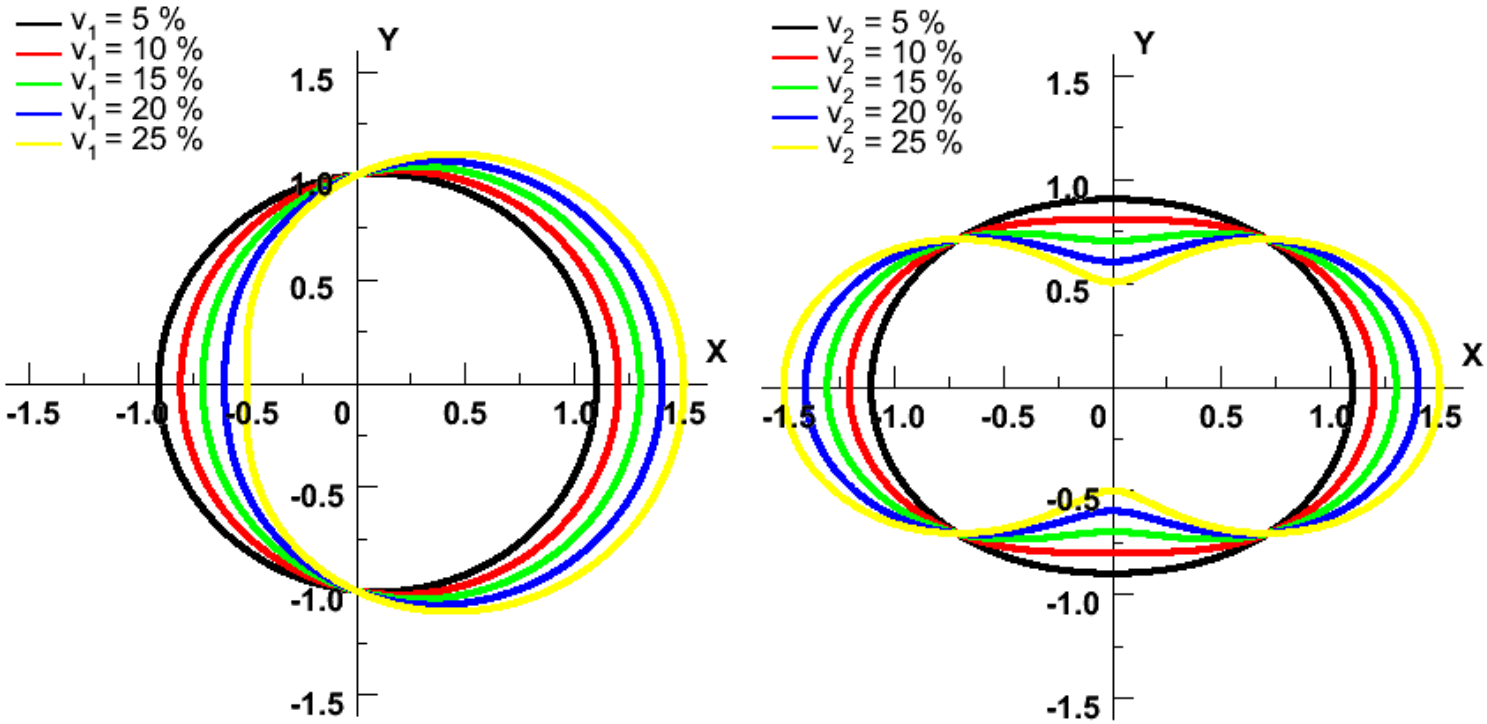
Motivation

- Elliptic Flow has been measured @ RHIC – PHENIX experiments. But Directed Flow has not been shown up to now because it is difficult to measure the strength of directed flow, which is very small in RHIC energies.
- Measurement of v_1 with three particle correlation which is expected to be less sensitive to non-flow contribution than other technique, such as reaction plane method, two particle correlation, are shown. We discuss its centrality, pseudo-rapidity dependence and comparison of other methods, data from other experiments.

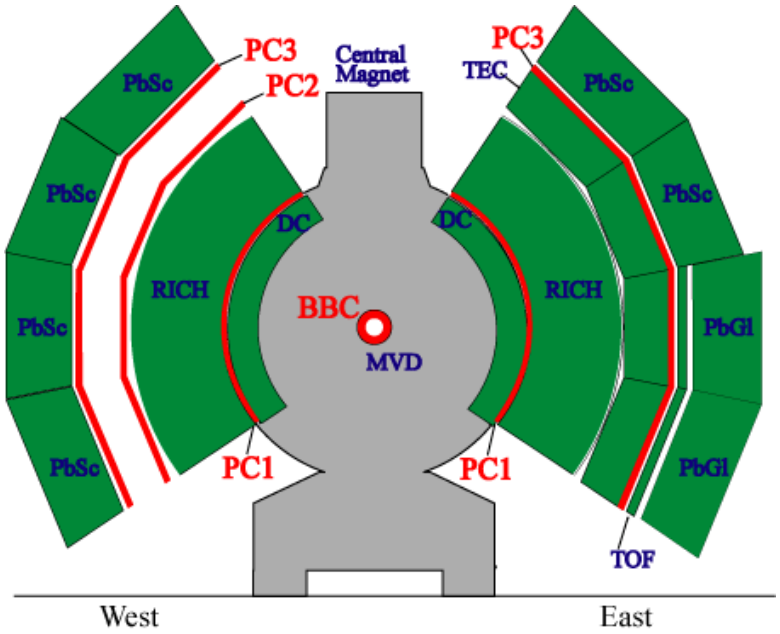
Azimuthal anisotropy
Directed/Elliptic Flow

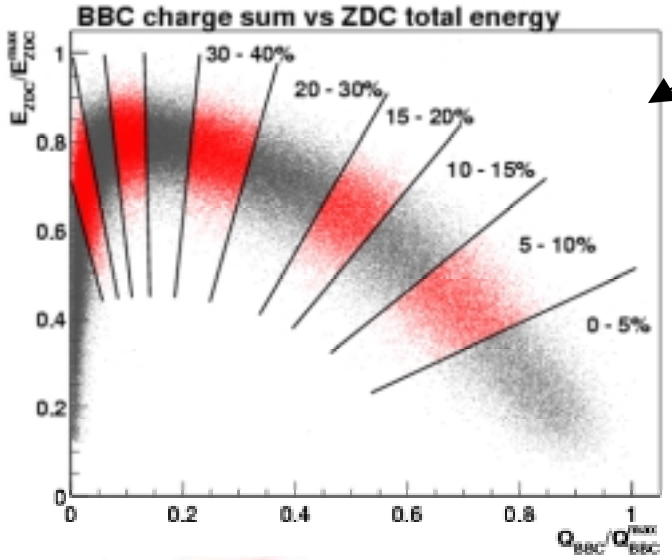
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos[n(\phi-\Psi)]\right)$$

v_n (n=1,2): strength of directed/elliptic flow
ϕ : azimuthal angle of detected particles
ψ : azimuthal angle of reaction plane



Experimental Setup PHENIX Detector





- Minimum Bias Trigger
  - BBC (Beam Beam Counter)
- Collision Vertex
  - BBC
- Centrality
  - BBC, ZDC (Zero Degree Calorimeter)
- Reaction Plane
  - BBC, DCH (Drift Chamber), PC (Pad Chamber)
- Tracking / Momentum
  - DCH, PC

Analysis method

- Reaction Plane method $v_1\{RP_1\}$, $v_2\{RP_2\}$

$$\left\langle e^{in(\phi-\Psi)} \right\rangle = v_n$$

- Two particle + Reaction Plane $v_1\{RP_2\}$

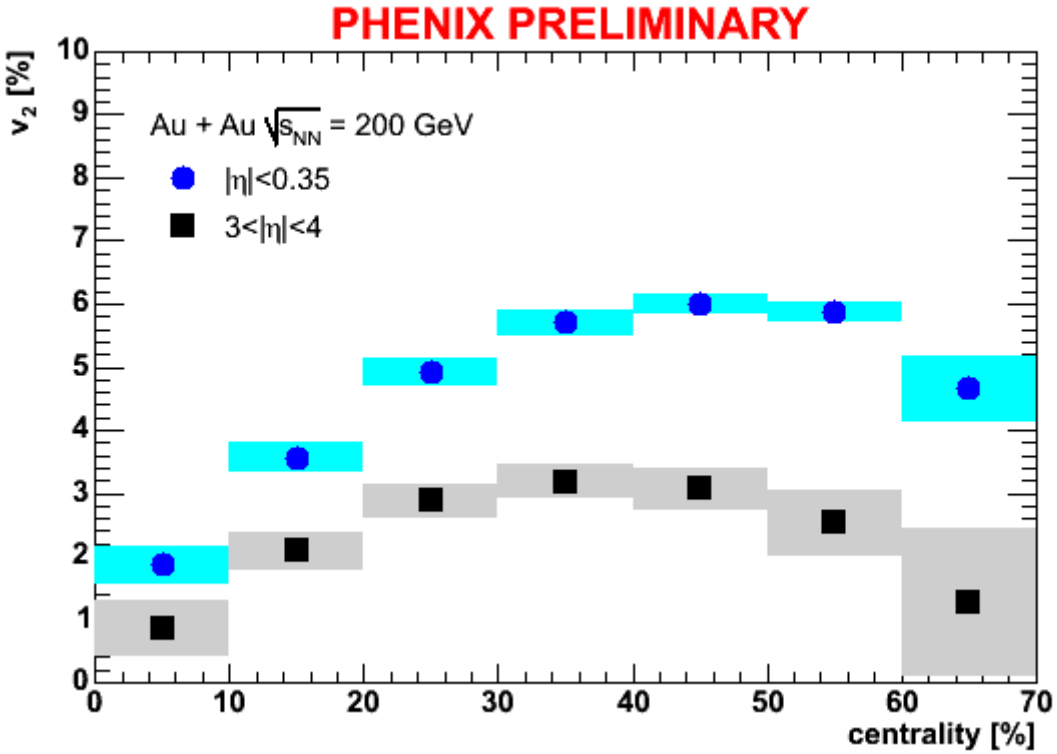
$$\left\langle e^{i(\phi_a+\phi_b-2\Psi_r)} \right\rangle = v_1^a v_1^b \left\langle \cos[2(\Psi_{true}-\Psi_r)] \right\rangle$$

- Three particle correlation $v_1\{3\}$

$$\left\langle e^{i(\phi_a+\phi_b-2\phi_c)} \right\rangle = v_1^a v_1^b v_2^c$$

Given by independent analysis.

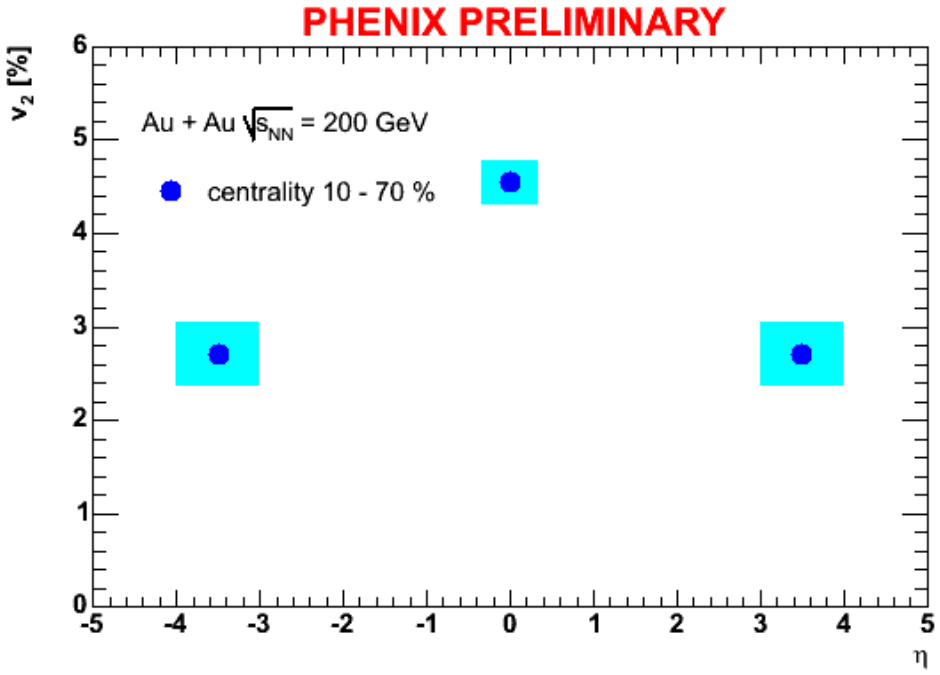
Elliptic Flow $v_2\{RP_2\}$
Comparison of Mid-rapidity ($|\eta|<0.35$) and Forward rapidity ($3<|\eta|<4$)

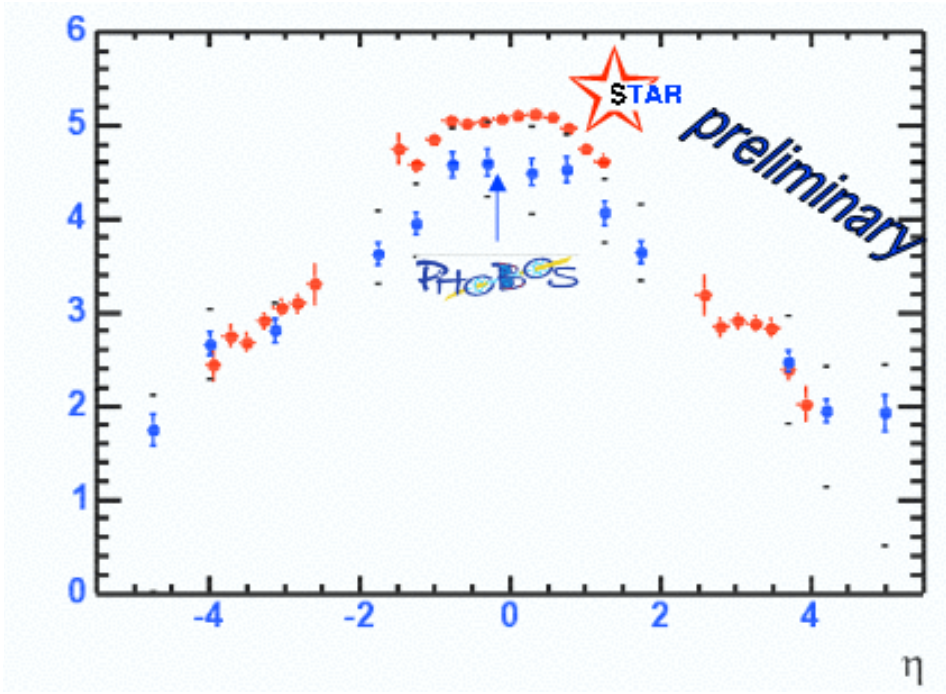


- Elliptic Flow measurement has been done by the standard reaction plane method @ mid-rapidity and forward rapidity.
- There is a little difference of shape between mid and forward rapidity.
  - Maximum of Mid. v_2 is around 40 – 50 %, while max of Forward v_2 is around 30 – 40 %.

Elliptic Flow

Comparison of PHENIX to other experiments

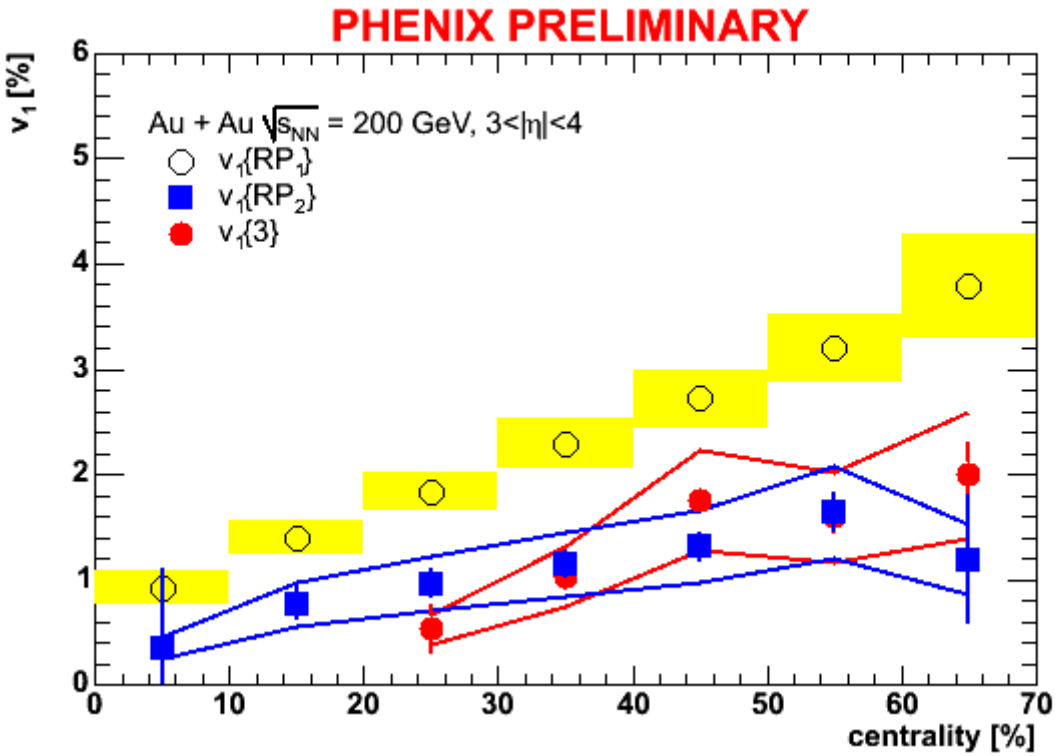




- PHENIX v_2 is consistent with PHOBOS and STAR results.

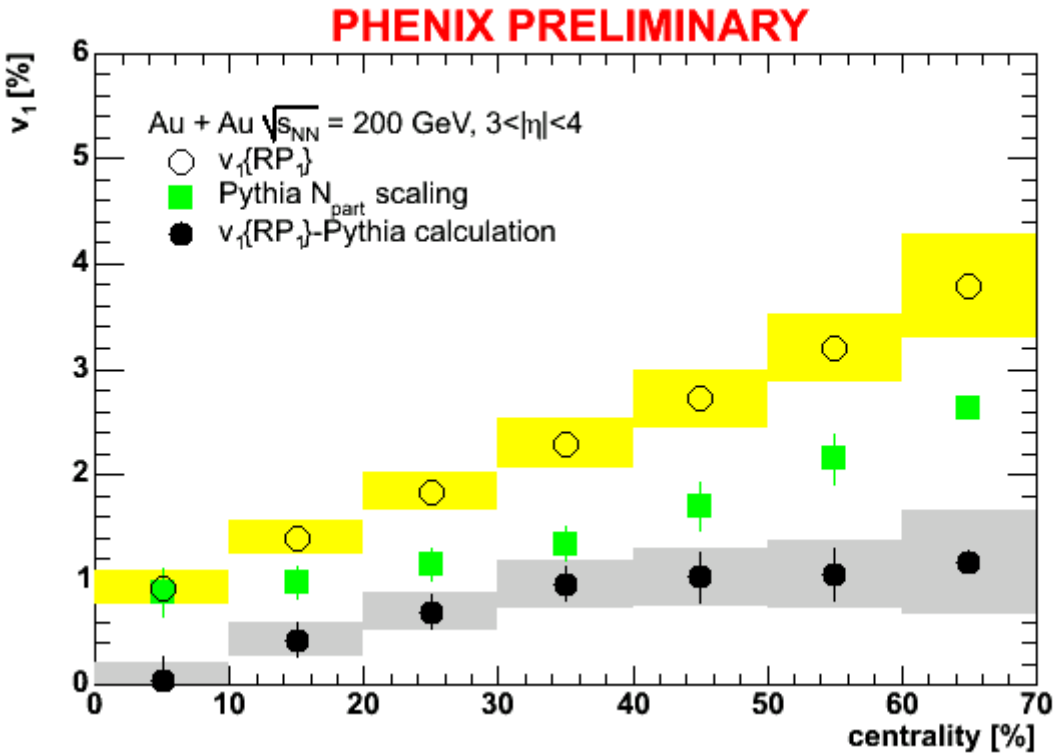
Directed Flow (3<|η|<4)

Comparison of several method



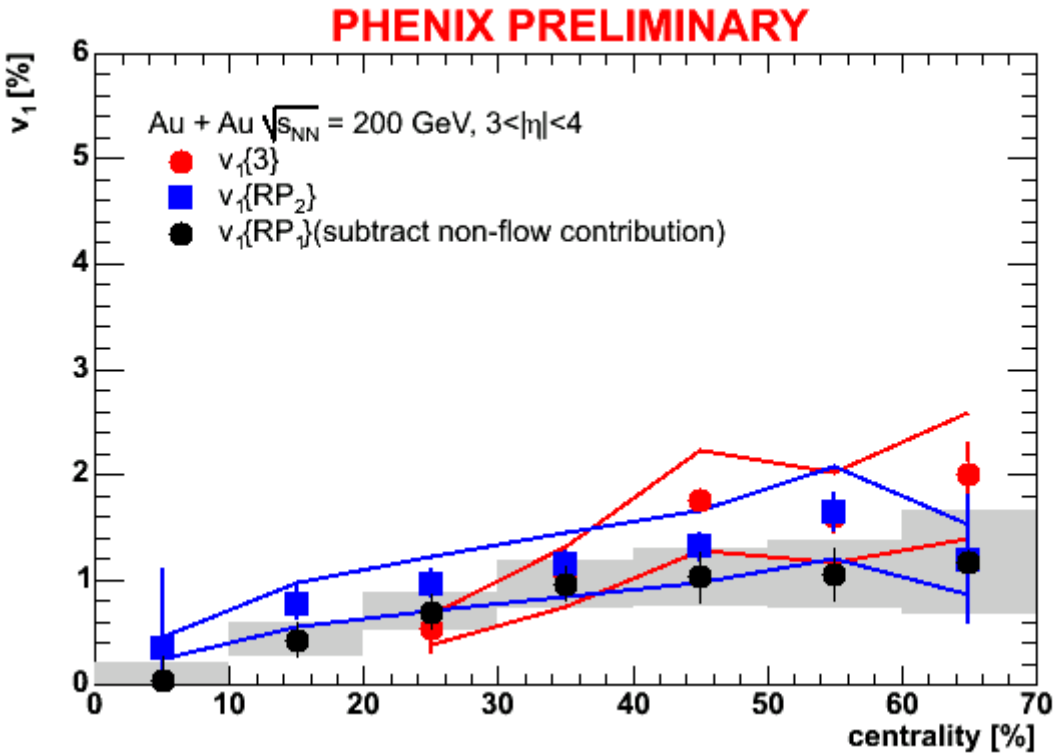
- First measurement of Directed Flow @ PHENIX.
  - $v_1\{RP_1\}$ increase linearly due to non-flow contribution.
  - $v_1\{RP_2\}$ and $v_1\{3\}$ are about 1 – 1.5 % and less than $v_1\{RP_1\}$. This indicate that these two method are insensitive to non-flow contribution as we expected.

Directed Flow (3<|η|<4)
Non-flow contribution



- Estimate non-flow contribution from Pythia simulation with scaling by number of participant (N_{part}).
- Extract only flow contribution (solid black) by subtracting Pythia results (green) from $v_1\{RP_1\}$ (open black).
  - True v_1 is about 1 %.

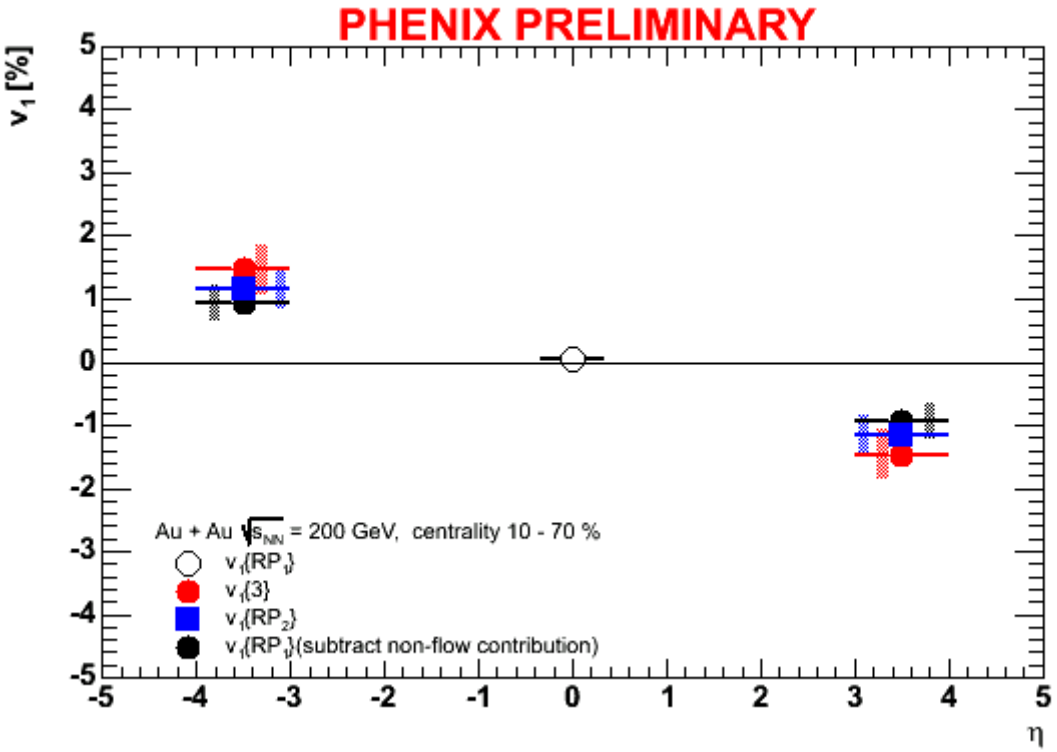
Directed Flow
Centrality dependence



- Finally results obtained from three independent analysis, where those are expected to be free from the non-flow contribution
  - Very good agreement within the error bars.

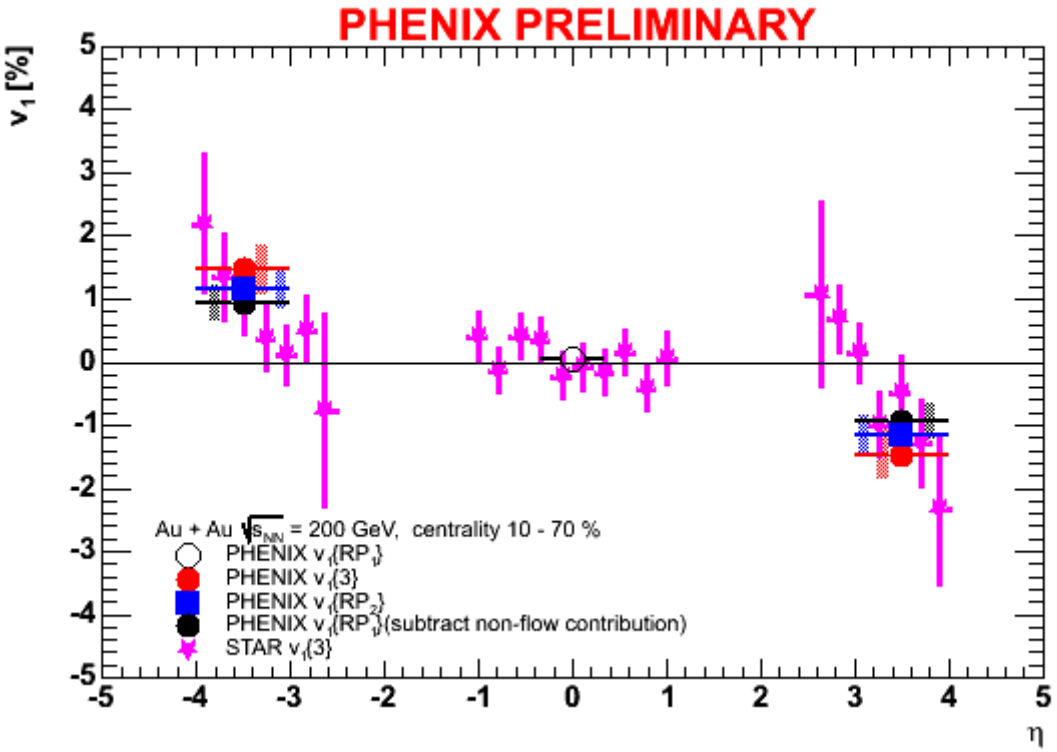
Directed Flow

Pseudo-rapidity dependence



- Integrated Directed Flow in 10 – 70 % centrality bins.
  - Sign of v_1 is defined by hand.
  - Systematic errors are shown by color bands.

Directed Flow
Comparison of PHENIX and STAR



- Comparison of PHENIX results to STAR $v_1\{3\}$.
  - All of the PHENIX results are consistent with STAR $v_1\{3\}$.

Summary

- First measurement of Elliptic Flow (v_2) in Forward rapidity ($3<|\eta|<4$) @ PHENIX.
  - v_2 ~ 3 %.
  - Consistent with PHOBOS and STAR.
- First measurement of Directed Flow (v_1) @ PHENIX.
  - v_1 ~ 0 @ mid-rapidity ($|\eta|<0.35$).
  - v_1 ~ 1 % @ forward rapidity ($3<|\eta|<4$).
- The results of $v_1\{RP_2\}$ and $v_1\{3\}$ indicate that v_2 @ RHIC is *in-plane* ($v_2 > 0$).
- $v_1\{RP_2\}$ and $v_1\{3\}$ are less sensitive than v_1 from the standard reaction plane method.
- The results of v_1 @ PHENIX is consistent with $v_1\{3\}$ from STAR experiments.